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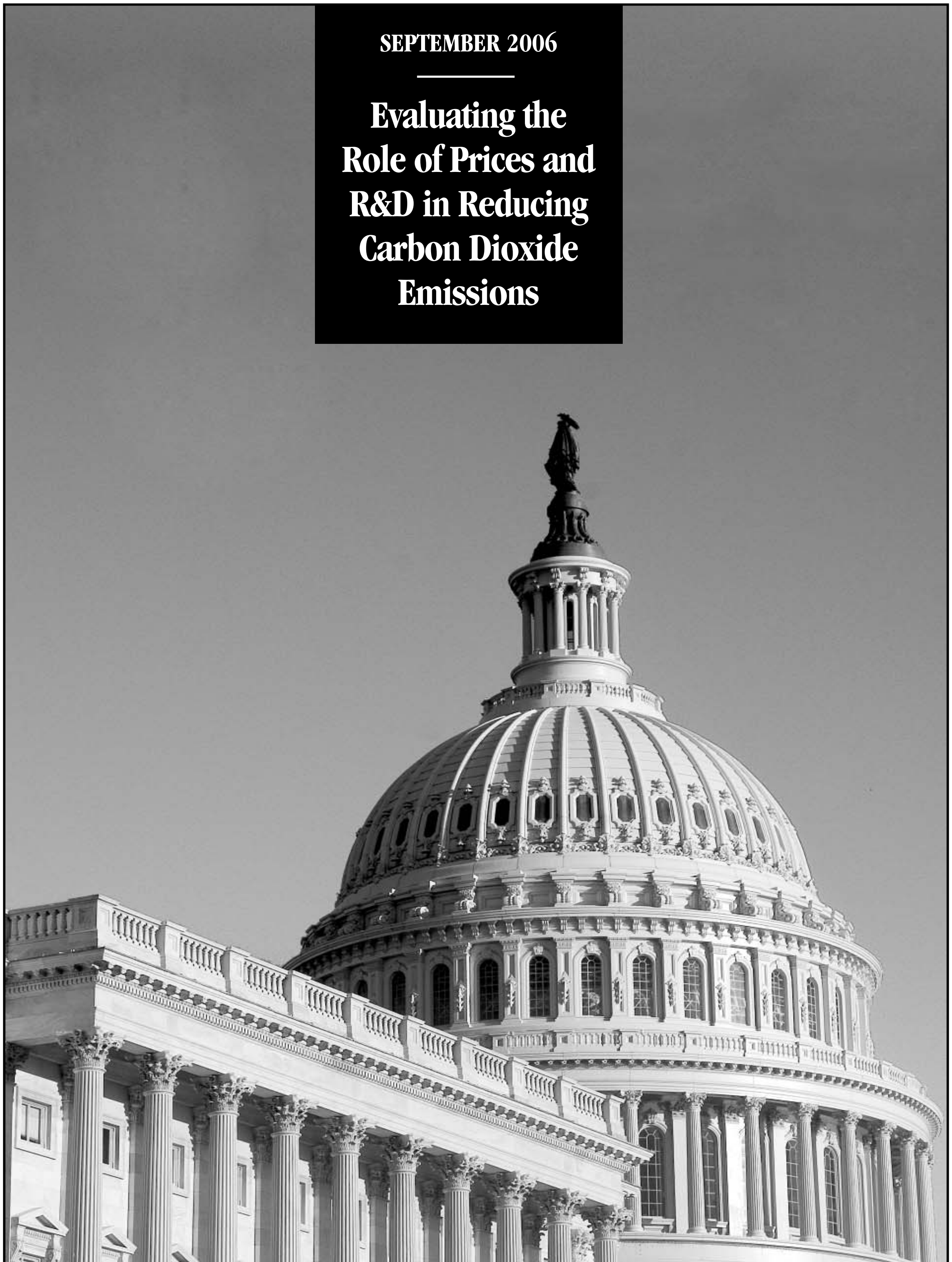

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CBO

PAPER

Evaluating the Role of Prices and R&D in Reducing Carbon Dioxide Emissions

September 2006

The Congress of the United States ■ Congressional Budget Office

Preface

The atmospheric concentration of greenhouse gases, most notably carbon dioxide, has gradually increased over the last century and, in the view of many climate scientists, is warming the global climate. Two policies—pricing carbon dioxide emissions and encouraging research and development of new carbon-reducing technologies—have been discussed as methods of limiting current and future emissions. This Congressional Budget Office (CBO) paper examines available research on the role that those policies might play in encouraging cost-effective reductions in emissions as well as analyses on whether it would be more efficient to implement the policies simultaneously or sequentially. The paper was prepared in response to a request from the Ranking Members of the Senate Committee on Energy and Natural Resources and the Senate Committee on the Environment and Public Works. In keeping with CBO's mandate to provide objective, impartial analysis, the paper makes no recommendations.

Terry M. Dinan prepared this paper under the supervision of Joseph Kile and David Moore. Colin Baker, Douglas Hamilton, Arlene Holen, Robert Shackleton, and Thomas Woodward provided comments. Outside of CBO, Henry Jacoby of the Massachusetts Institute of Technology, David Popp of the University of Syracuse, Richard Richels of the Electric Power Research Institute, and David Montgomery of Charles River Associates International provided comments. (The assistance of external reviewers implies no responsibility for the final product, which rests solely with CBO.)

Christine Bogusz edited the paper, and Loretta Lettner proofread it. Maureen Costantino prepared the paper for publication, took the cover photo, and designed the cover, and Lenny Skutnik printed copies of the paper. Simone Thomas produced the electronic version for CBO's Web site (www.cbo.gov).

Donald B. Marron

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Acting Director

September 2006

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CHAPTER

1

Summary and Introduction

Several important human activities—most notably the worldwide burning of coal, oil, and natural gas—are gradually increasing the concentrations of carbon dioxide and other greenhouse gases in the atmosphere and, in the view of many climate scientists, are gradually warming the global climate. That warming, and any long-term damage that might result from it, could be reduced by restraining the growth of greenhouse gas emissions and ultimately limiting them to a level that stabilized atmospheric concentrations.

The magnitude of warming and the damages that might result are highly uncertain, in part because they depend on the amount of emissions that will occur both now and in the future, how the global climate system will respond to rising concentrations of greenhouse gases in the atmosphere, and how changes in climate will affect the health of human and natural systems. The costs of restraining emissions are also highly uncertain, in part because they will depend on the development of new technologies.[1] From an economic point of view, the challenge to policymakers is to implement policies that balance the uncertain costs of restraining emissions against the benefits of avoiding uncertain damages from global warming or that minimize the cost of achieving a target level of concentrations or level of annual emissions.

Researchers have studied the relative efficacy—as well as the appropriate timing—of various policies that might discourage emissions of carbon dioxide (referred to as carbon emissions in the rest of this paper), which makes up the vast majority of greenhouse gases, and restrain the growth of its atmospheric concentration. This paper presents qualitative findings from that research, which are largely independent of any particular estimate of the costs or benefits of reducing emissions. The paper's conclusions are summarized below.

Policies for Reducing Carbon Emissions

The possibility of climate change involves two distinct "market failures" that prevent unregulated markets from achieving the appropriate balance between fossil fuel use and changes in climate. One market failure involves the external effects of emissions from the combustion of fossil fuels—that is, the costs that are imposed on society by the use of fossil fuels but that are not reflected in the prices paid for them. The other market failure is a general underinvestment in research and development (R&D) that occurs because investments in innovation may yield "spillover" benefits to society that do not translate into profits for the innovating firm. The first market failure yields inefficiently high use of fossil fuels; the second yields inefficiently low R&D.

Because there are two separate market failures, an efficient response is likely to involve two separate types of policies:

- One type of policy would reduce carbon emissions by increasing the costs of emitting carbon, both in the near term and in the future, to reflect the damages that those emissions are expected to cause.
- The other type of policy would increase federal support for R&D on various technologies that could help restrain the growth of carbon emissions and would create spillover benefits.

Policymakers could increase the cost of emitting carbon by setting a price on those emissions. That could be accomplished by taxing fossil fuels in proportion to their

1. For a discussion of the uncertainty underlying estimates of the costs and benefits of reducing emissions and the implications for policy formation, see Congressional Budget Office, *Uncertainty in Analyzing Climate Change: Policy Implications* (January 2005).

carbon content (which is released when the fuels are burned) or by establishing a “cap-and-trade” program under which policymakers would set an overall cap on emissions but allow fossil fuel suppliers to trade rights (called allowances) to those limited emissions. Either a tax or a cap-and-trade program would cause the prices of goods and services to rise to reflect the amount of carbon emitted as a result of their consumption. To the extent that a carbon tax or allowance price reflected the present value of expected damages, [2] such policies would encourage users of fossil fuels to account for the costs they impose on others through their emissions of greenhouse gases.

Researchers generally conclude that the appropriate price for carbon would be relatively low in the near term but would rise substantially over time, resulting in relatively modest reductions in emissions in the near term followed by larger reductions in the future. Phasing in price increases would allow firms to gradually replace their stock of physical capital associated with energy use and to gain experience in using new technologies that emit less carbon. Firms would have an incentive to invest in developing new technologies on the basis of their expectations about future prices for emissions.

Federal support could be provided for the research and development of technologies that would lead to lower emissions. Such technologies could include improvements in energy efficiency; advances in low- or zero-emissions technologies (such as nuclear, wind, or solar power); and development of sequestration technologies, which capture and store carbon for long periods. Federal support would probably be most cost-effective if it went toward basic research on technologies that are in the early stages of development. Such research is more likely to be underfunded in the absence of government support because it is more likely to create knowledge that is beneficial to other firms but that does not generate profits for the firm conducting the research.

2. By discounting future damages to the present, the costs and benefits of undertaking actions that reduce climate change are placed on a common temporal footing. The discount rate chosen to compare avoided future damages (benefits) and costs is controversial. For a discussion, see Congressional Budget Office, *Uncertainty in Analyzing Climate Change* and *The Economics of Climate Change: A Primer* (April 2003).

The Interaction and Timing of Policies

Pricing and R&D policies are neither mutually exclusive nor entirely independent—both could be implemented simultaneously, and each would tend to enhance the other. Pricing policies would tend to encourage the use of existing carbon-reducing technologies as well as provide incentives for firms to develop new ones; federal funding of R&D would augment private efforts; and successful R&D investments would reduce the price required to achieve a given level of reductions in emissions.

Neither policy alone is likely to be as effective as a strategy involving both policies. Relying exclusively on R&D funding in the near term, for example, does not appear likely to be consistent with the goal of balancing costs and benefits or the goal of minimizing the costs of meeting an emissions reduction target. At any point in time, there is a cost continuum for emissions reductions, ranging from low-cost to high-cost opportunities. Unless R&D efforts virtually eliminated the value of near-term reductions in emissions (an outcome that appears unlikely given reasonable assumptions about the payoff of R&D efforts), waiting to begin initial pricing (to encourage low-cost reductions) would increase the overall cost of reducing emissions in the long run.

Near-term reductions in emissions achieved with existing technologies could be valuable even if fundamentally new energy technologies would be needed to prevent the buildup of greenhouse gases in the atmosphere from reaching a point that triggered a rapid increase in damages. Near-term reductions could take advantage of low-cost opportunities to avoid adding to the stock of gases in the atmosphere and could allow additional time for new technologies to be developed and put in place. That additional time could prove quite valuable, given that R&D efforts are highly uncertain and that the process of putting new energy systems in place could be slow and costly.

Determining the appropriate mix of policies to address climate change is complicated by the fact that future policies would be layered on a complex mix of current and past policies, all of which affect today’s use of fossil fuels and their alternatives as well as the amount of R&D. The analyses reviewed in this paper typically do not account for existing policies or for the administrative costs of implementing a carbon-pricing program or of initiating a larger (and perhaps redesigned) R&D program for carbon-reducing technologies. However, the qualitative

conclusion reached in those analyses—that costs would be minimized by a combination of gradually increasing emissions prices coupled with subsidies for R&D—is not likely to be affected by such considerations.[3]

A Global Concern

The causes and consequences of climate change are global, and reductions in U.S. emissions alone would be unlikely to have a significant impact. Cost-effective mitigation policies would require coordinated international efforts and would involve overcoming institutional barriers to the diffusion of new technologies in developing countries, such as India and China. If a domestic carbon-pricing program significantly increased the prices of U.S.-produced goods—and was not matched by efforts to reduce emissions in other countries—it could cause carbon-intensive industries to relocate to countries without similar restrictions, diminishing the environmental benefits of a domestic program.

However, successful domestic R&D efforts, whether funded by the public or private sector, could lower the costs of reducing carbon emissions in other countries as well as within the United States. Some new technologies, such as those that yielded improvements in energy efficiency, might be deployed without additional incentives. Other innovations, such as sequestration technologies or alternative energy technologies that reduce carbon emissions but cost more than their fossil-fuel-based alternatives, would be unlikely to be deployed without financial incentives to reduce carbon emissions.

3. An exception to this would be if the net benefits of reducing carbon emissions were too small to justify the costs of administering either or both policies.

CHAPTER

2

Policies for Reducing Carbon Emissions

Rising emissions of carbon dioxide from the combustion of fossil fuels, and the resulting increases in the concentration of carbon in the atmosphere, raise concerns about the prospect of climate change and the costs that could be imposed on society. If policymakers chose to take action to reduce the level of carbon emissions, they would face two distinct "market failures" that would prevent the free market from settling on the amount of carbon emissions that would be best for society. In general, distinct market failures are best addressed by separate policy instruments.

One market failure arises because the combustion of fossil fuels may create external costs that are borne by society as a whole—particularly by future generations—but are not reflected in the prices that people pay for those fuels, or for the services that the fuels provide. As a result, firms, households, governments, and other organizations would be likely to consume more fossil fuels—and emit more carbon—than would be best for society. Setting a price on carbon emissions that reflected their external costs would correct that market failure.

The other market failure arises because the research and development of new technologies for reducing carbon emissions are likely to result in spillover benefits. Such benefits are realized by other firms as a result of the innovating firm's R&D effort but do not generate profits for the innovating firm. Thus, firms tend to engage in less R&D on carbon-reducing technologies than would be best for society. Increasing public funding for the development of new carbon-reducing technologies would correct that failure, as long as the spillover benefits of such activities exceeded their costs.

Current policies in the United States both encourage and discourage firms and households from using fossil fuels, but no existing policy provides systematic incentives for users to account for the potential costs of carbon emissions. Current U.S. policies also provide subsidies for R&D that at least partially compensate for spillover benefits; determining whether those subsidies are sufficient, however, is beyond the scope of this paper.

Pricing Carbon to Address the External Costs of Emissions

The costs of carbon emissions could be built into the price of consuming fossil fuels directly by taxing such fuels or indirectly by allowing the market to set a price on carbon emissions through a cap-and-trade program. A tax could be imposed on fossil fuel producers and importers on the basis of the carbon content of their fuels, a so-called upstream tax. Alternatively, an upstream cap-and-trade program would require producers or importers to pay for the right (called an allowance) to sell goods and services that ultimately led to carbon emissions. The cost of the tax or the allowance, like any other cost, would be reflected in the price producers charged for goods and services that resulted in carbon emissions (see Box 2-1). Either approach could be designed to provide firms with an incentive to capture and sequester carbon emissions, thus reducing net emissions into the atmosphere, as well as to reduce their initial emissions.

The Effects of Pricing

Establishing a price for carbon emissions would cause the costs of using fossil fuels to rise to reflect their carbon content, with the largest percentage increase for coal, followed by oil and then natural gas.[1] Higher fossil fuel costs and the resulting increases in the prices of services, such

1. Under an upstream system, fossil fuel producers and importers would pay the tax or purchase the allowance, and fossil fuel prices would increase accordingly. Those price increases would filter through the economy, increasing the prices of goods and services in proportion to the carbon emissions that their production and consumption generated.

Box 2-1.

How Emissions Taxes and Cap-and-Trade Policies Would Work

Policymakers could take several approaches to limiting carbon dioxide emissions. One approach—a tax on those emissions—would raise the cost of emitting carbon dioxide, thereby encouraging households and firms to cut their emissions as long as the cost of doing so was less than the tax. That approach would set an upper limit on the cost of individual reductions in emissions (at the level of the tax) but would not ensure that any particular emissions target was met.

A second approach—a cap-and-trade program—would set an overall limit on the level of carbon dioxide emissions but leave the decisions about where and how the necessary reductions should be made to households and firms. Under that approach, policymakers would establish an overall cap on emissions but allow regulated firms to trade rights to those emissions, called allowances. That trading would permit firms that could reduce their emissions most cheaply to sell some of their allowances to firms that faced higher costs to reduce their emissions. Such an approach would limit the overall level of emissions but would not place any explicit limit on the cost of individual reductions.

Under a third, hybrid approach, policymakers would set an overall cap on total emissions, but they would also establish an upper limit on the price of allowances, referred to as a "safety valve" price. If the price of allowances rose to the safety-valve price, the government would sell as many allowances as was necessary to maintain that price. Thus, if the safety valve was triggered, the actual level of emissions would exceed the cap. The cap would be met only if the price of allowances never rose above the safety-valve price.

Research has shown that, given the uncertainty associated with the costs and benefits of carbon-reduction policies, a tax on carbon dioxide emissions (or a cap-and-trade program with a safety valve) would result in significantly higher expected net benefits than a cap-and-trade program with a fixed cap.[1] A tax would motivate people to limit their emissions up to the point at which the costs of doing so were equal to the tax. If actual costs were less than, or greater than, anticipated, people would limit their emissions more than, or less than, policymakers projected. However, emissions would be reduced up to the point at which the cost of doing so was equal to the expected benefits (provided that the tax was set at the efficient level). In contrast, a strict cap on emissions could result in actual costs that were far greater (or less than) expected and, therefore, exceeded (or fell below) the expected benefits.

Either a tax on carbon dioxide emissions or a cap-and-trade program could be designed to provide incentives for firms to sequester carbon. For example, a tax credit for sequestration could be implemented in conjunction with a tax on carbon dioxide emissions. Likewise, firms could be permitted to reduce their allowance requirements by sequestering carbon.

1. For a more detailed discussion of this point, see Congressional Budget Office, *Limiting Carbon Dioxide Emissions: Prices Versus Caps*, CBO Issue Brief (March 15, 2005).

as electricity, would provide incentives for emitters to make changes in their behavior or operations that would conserve energy (such as driving less and turning down thermostats); to invest in more-efficient appliances and equipment; and to make greater use of renewable fuels to heat water and power vehicles. The carbon price would also provide an incentive for electricity producers to decrease the carbon intensity of the electricity that they produced. That decrease could be accomplished by switching to fossil fuels with lower carbon contents (for example, from coal to natural gas), by generating electricity from nuclear power or renewable fuels, or from converting coal to gas and capturing and sequestering the carbon.[2] The magnitude of the incentive created for those activities would depend on the price of the carbon.[3]

Carbon pricing would encourage cost-effective reductions in emissions at any given point in time because it would provide firms, households, governments, and other organizations with a uniform incentive to undertake the broad array of activities that would reduce emissions. A worldwide pricing policy would be more efficient than one that was limited to the United States because carbon is a global pollutant. A uniform worldwide price for carbon would provide an incentive for emitters that could make reductions at the lowest cost to do so, regardless of national boundaries. Establishing a domestic price for carbon emissions would minimize the cost of achieving a given level of reductions within the United States, but that same quantity of reductions could be obtained at a lower cost under coordinated policies that set an equal price for carbon emissions throughout the world.

Setting a current price for carbon emissions and announcing planned future carbon prices not only would induce firms and households to change their behavior but also would increase their demand for technologies that would reduce emissions. That increase in demand would in turn create incentives for firms to research and develop new methods of improving energy efficiency, producing energy from renewable sources, and sequestering carbon.[4] Moreover, as firms gain more experience with low-carbon technologies, they may learn how to produce them at a lower cost.[5]

Some researchers suggest that future carbon taxes would not provide adequate incentives for R&D if a firm anticipated that policymakers might lower the carbon tax—and thus reduce the firm's return on its R&D investment—once it successfully developed a new technology. That concern could be valid only for a technology that would be expensive to develop and, once developed, could reduce a significant fraction of the world's carbon emissions at a low per-unit price (see Box 2-2).

Setting Prices

A carbon tax or cap, and the resulting increase in fossil fuel prices, would impose costs on the economy; consequently, policymakers may wish to balance those costs against the anticipated reduction in climate-related damages. An efficient per-ton price for carbon would reflect the damages that are anticipated from a ton of carbon emissions. Damages from today's emissions would occur in the future, and their expected magnitude can only be

2. Electricity producers would have incentives to sequester carbon only if they were required to pay the tax directly or to hold the allowance for each ton of carbon they emitted. If the tax or allowance requirement was imposed upstream—on producers and importers of fossil fuels—electricity producers would have an incentive to minimize their use of carbon-intensive fuels, but they would not have an incentive to sequester carbon emissions unless special provisions were made. See Congressional Budget Office, *Issues in the Design of a Cap-and-Trade Program for Carbon Emissions*, CBO Issue Brief (November 25, 2003).

3. Note that higher prices for fossil fuels resulting from an increasing scarcity of those fuels would also promote decreased use. However, fossil fuel use would still exceed the socially efficient amount because the prices would not reflect the external costs of carbon emissions.

4. Studies have demonstrated the effectiveness of higher energy prices in stimulating R&D on renewable energy technologies. For example, see David Popp, "Induced Innovation and Energy Prices," *American Economic Review*, vol. 92 (2002), pp. 160-180.

5. For a discussion of how near-term abatement can lower the cost of future carbon reductions by creating opportunities for learning by doing, see Michael Grubb, "Technologies, Energy Systems, and the Timing of CO_2 Abatement," *Energy Policy*, vol. 25, no. 2 (1997), pp. 159-172; Arnulf Grubler and Sabine Messner, "Technological Change and the Timing of Mitigation Measures," *Energy Economics*, vol. 20 (1998), pp. 495-512; and B.C.C. van der Zwann and others, "Endogenous Technological Change in Climate Change Modeling," *Energy Economics,* vol. 24 (2002), pp. 1-19.

Box 2-2.

Would Taxes on Carbon Dioxide Emissions Spur Research and Development of New Technologies?

A tax on carbon dioxide emissions would create a market for technologies that could reduce those emissions. Emitters would find it worthwhile to purchase those technologies provided that the cost of doing so was less than the cost of paying the tax. Current taxes would create incentives for current reductions in emissions, and expectations of future taxes would provide firms with an incentive to invest in the research and development, or R&D, of new technologies.

Some research has suggested that announced future taxes may not provide an adequate incentive for firms to develop a fundamentally new technology for reducing carbon dioxide emissions. That research is based on the argument that the government may have an incentive to reduce carbon taxes, and correspondingly returns to investors, after costly R&D was undertaken. Specifically, policymakers might announce one set of future taxes—which would reflect the full costs of developing and deploying such a technology—but then reduce those taxes once the technology was developed.[1] If that occurred, emitters would be willing to pay less for the new technology than the initially announced taxes would suggest. If firms anticipated that policymakers would reduce the tax once the new technology was introduced—and that the tax reduction would cause the innovating firm to be unable to recoup some of its R&D costs—then firms would be less willing to undertake the initial R&D investment to develop the technology.[2]

What set of circumstances might lead to the outcome described above? Policymakers might be motivated to reduce taxes on carbon dioxide emissions after a firm successfully developed a new technology in the case of a technology that could reduce a significant fraction of the world's emissions—for example, by producing carbon-free energy—at a low and relatively constant per-unit cost. In that case, the new technology would warrant a decrease in the tax because it would be expected to so greatly reduce the future atmospheric concentration of carbon dioxide that the marginal damage from current and future emissions

1. For a discussion of this argument, see W. David Montgomery and Anne E. Smith, "Price, Quantity, and Technology Strategies for Climate Change Policy," in *Human-Induced Climate Change: An Interdisciplinary Assessment* (Boston, Mass.: Cambridge University Press, forthcoming).
2. As the amount of emissions reductions provided by the new technology increases, the price premium necessary to cover the fixed R&D costs decreases.

estimated with a high degree of uncertainty.[6] Provided that the price of carbon was set equal to the current value of the damages anticipated from today's emissions, carbon pricing would give emitters an incentive to undertake reductions when the cost of doing so would be outweighed by the expected benefit—that is, the avoided damage.

The relationship between near-term and future carbon prices would determine the pattern of reductions in emissions over time. In general, gradually rising prices have been found to be most efficient—that is, most likely to

6. That measure of expected damages depends on many uncertain factors, including the time that carbon lingers in the atmosphere, the path of emissions in the future, the change in climate associated with higher atmospheric stocks of carbon, the physical damages associated with changes in climate, and the value of those damages. For a discussion of those factors, see Congressional Budget Office, *Uncertainties in Analyzing Climate Change: Policy Implications* (January 2005).

Box 2-2.

Continued

would be lessened.[3] Maintaining the tax once the new technology was introduced would induce some reductions in emissions that would be unwarranted on the basis of the resources required to achieve them and the now lower benefits (avoided damages) that they would create. An efficient tax reduction would be more likely to prevent the innovating firm from recouping its R&D costs if those costs were large and if the cost of providing an additional unit of the new technology was relatively constant. Thus, the contention that a firm would be dissuaded from developing a new technology out of concern that its introduction would trigger a tax reduction that would prevent the firm from recovering its R&D costs could be valid only for a technology that met two criteria: it would be very expensive to develop, and it would be able to reduce a significant share of the world's carbon dioxide emissions at a low, and relatively constant, per-unit cost.

A technology that fits that case has not been identified, but some so-called silver bullet technologies are being explored. Concern that policymakers might lower a tax on carbon dioxide emissions once such potential technologies were developed could strengthen the case for funding research on them; nevertheless, that concern would be unlikely to pose a general disincentive to other forms of technological innovation that could play an important role in addressing climate change. Finally, even in the case of a silver bullet technology, policymakers could be reluctant to make a tax reduction that eliminated the innovating firm's return on its R&D investment if such an action was expected to discourage future R&D on other carbon-reducing technologies.

Concerns that policymakers might lessen the stringency of the policy once a technological innovation occurred are less likely to apply to a cap-and-trade program that does not include a safety-valve price (see Box 2-1). In that case, technological innovations would encourage policymakers to increase—not decrease—the stringency of the cap (because the cost of achieving any given cap would be reduced), and firms' ability to recoup their R&D expenses would depend primarily on their ability to patent their innovations. (Spillover benefits could still provide a rationale for using public funds to supplement private R&D efforts.) Inclusion of a safety valve could cause a cap-and-trade program to function in a similar manner to a carbon dioxide tax and, thus, could lead to concerns about a tax decrease following a technology innovation under the same set of circumstances described above.

3. Specifically, policymakers would find it efficient to reduce the tax to the point at which the firm's marginal cost of reducing a ton of carbon dioxide with the new technology, which would increase as more of the new technology was deployed, was equal to the marginal damage of emitting an additional ton of carbon dioxide, which would decline as more of the new technology was deployed. The efficient tax would just cover the cost of producing the marginal unit of the new technology, but the firm would earn profits on inframarginal units (which have production costs below the tax). Firms' profits on those inframarginal units may not fully cover the cost of developing the new technology. That situation is most likely to occur when the cost of producing an additional unit of the technology is relatively insensitive to the amount produced and when the R&D costs are very large. Technologies that were not expected to provide enough reductions in emissions to significantly lower the atmospheric concentration of carbon dioxide in the future would increase the efficient amount of emissions reductions but would not be expected to trigger a tax decrease. For a demonstration of the latter point, see Lawrence H. Goulder and Stephen H. Schneider, "Induced Technological Change and the Attractiveness of CO_2 Abatement Policies," *Resource and Energy Economics*, vol. 21 (1999), pp. 211-253.

result in a pattern of reductions that would best balance costs and benefits over the long run.[7]

Gradually rising carbon prices would lead to steady reductions in emissions (relative to the baseline trend). Phasing in reductions would allow firms to gradually replace the capital stock that affects carbon emissions—including housing stock, appliances, automobiles, industrial equipment, and power plants—with newer capital that would lead to lower emissions, such as more energy-efficient houses, or power plants that generate electricity from sources that do not emit carbon. In the absence of economic incentives to reduce carbon emissions, such replacements would be unlikely to occur, and a new generation of carbon-intensive capital stock could be put in place—perhaps necessitating premature retirements of that stock in the future.[8]

By providing incentives for relatively low-cost reductions in emissions today and delaying more significant reductions until the future, policymakers would allow time for new technologies to develop. Analysts' opinions about the appropriate timing of reductions in emissions vary, in part, because of different assumptions about how likely it is that technological advances would occur and how costly achieving those advances would be.[9]

Current Policies That Provide Incentives and Disincentives for Fossil Fuel Use

Numerous policies affect the consumption of fossil fuels. Policies that directly or indirectly encourage the use of fossil fuels include federal support for highway construction and various tax provisions that promote the domestic production of oil and natural gas. Policies that discourage the use of fossil fuels include the federal gasoline tax, subsidies for mass transit, and various tax provisions that promote alternative fuels such as ethanol, biogas, and coal synfuels.

Those policies provide conflicting incentives for households and firms to use fossil fuels. Further, even the policies that discourage fossil fuel use do not do so on the basis of the extent to which the fossil fuels contribute to climate change. In contrast, a tax or cap on carbon emissions would provide an incentive for households and firms to take those external costs into account—providing the greatest discouragement for the use of coal, which releases the most carbon when it is burned.[10] Such a tax or cap would encourage a more complete range of activities that could reduce carbon emissions (including im-

7. As a first approximation, intertemporal efficiency would require that carbon prices rise at the real (inflation-adjusted) rate of interest minus the rate at which carbon was absorbed into the ocean and thus disappeared from the atmosphere. See William D. Nordhaus, *Life After Kyoto: Alternative Approaches to Global Warming Policies*, Working Paper No. 11889 (Cambridge, Mass.: National Bureau of Economic Research, December 2005), p. 9. Because damages stem from the accumulation of carbon in the atmosphere, they are expected to be greater in the future than in the present. The efficient price of carbon increases over time to represent the growing weight placed on future damages as they become closer in time.

8. The baseline capital stock could become more or less carbon intensive as the relative prices of fossil fuels and alternative technologies changed over time. However, in the absence of carbon pricing—or in anticipation of it—there would be no incentive for firms or households to make choices on the basis of the carbon emissions that resulted from the different technologies. As a result, even models that suggest that a stated target for the atmospheric concentration of carbon could be met with little divergence from baseline emissions in the near term find that some near-term reductions would have value (this is reflected by a positive "shadow price" for such reductions). For an example, see Richard Richels and Jae Edmonds, "The Economics of Stabilizing Atmospheric CO_2 Concentrations," *Energy Policy*, vol. 23, no. 4/5 (1995), pp. 373-378. Information about the shadow price of carbon was based on personal communication with the lead author.

9. Some models incorporate information about specific alternative energy technologies, including their initial price and the prospects that their costs would fall. Those models—called bottom-up models because of the detail that they contain on specific technologies—tend to be relatively optimistic about the prospects for technological advancement but typically fail to represent the costs that might be associated with research efforts. Top-down models, in contrast, tend to have better information on the links between environmental policy and macroeconomic performance (better capturing the costs of R&D efforts), but they have considerably less detail about specific alternative energy technologies and tend to be less optimistic about the prospects of cost reductions. For a more complete discussion of the strengths and limitations of top-down and bottom-up models, see Leon E. Clarke and John P. Weyant, "Modeling Induced Technological Change: An Overview," in Arnulf Grubler, Nebojsa Nakiconovic, and William D. Nordhaus, eds., *Technological Change and the Environment* (Washington, D.C.: Resources for the Future, 2002), pp. 343-349; and David Popp, "Entice-BR: The Effects of Backstop Technology and R&D on Climate Policy Models," *Energy Economics,* vol. 28 (2006), pp. 189-191.

10. Carbon emissions would be roughly 80 percent higher if a given amount of heat was generated by coal (or 50 percent higher if generated by fuel oil) rather than by natural gas. See www.epa.gov/airmarket/epa-ipm/chapter8.pdf.

provements in energy efficiency, the use of renewable energy sources, and, depending on the design, sequestration), not just those that are targeted by a specific tax credit.

Subsidizing R&D Efforts to Account for Spillover Benefits

Even if the external costs of carbon were incorporated into prices for fossil fuels, firms might invest less in research and development than would be best from society's point of view. That outcome would be likely if firms' resulting profits were expected to fall short of society's benefits. The extent to which that outcome would occur depends, in part, on the nature of the research, existing patent laws, and existing tax provisions.

The Benefits of Supporting R&D

The development of some technologies to reduce carbon emissions entails basic scientific research. That basic research may create knowledge that is beneficial to society; however, because it may not result in patentable inventions, such research may be underfunded in the absence of federal support. The role of basic research—and the resulting creation of spillover benefits—is likely to be particularly large in developing fundamentally new technologies that are a long way from the marketplace but that could provide large amounts of carbon-free energy, or carbon sequestration, at a low cost. (For example, some researchers have considered the possibility that hydrogen fuel could be manufactured from high-efficiency solar processes or that low-resistivity power lines could distribute solar electricity between continents, time zones, and day/night cycles.)[11]

Other research is likely to be tied to the development of technologies that are much closer to the marketplace (for example, improvements in vehicles' fuel efficiency or in the generation of electricity from wind) and, thus, firms would be more likely to profit from that research. However, even if patents allowed firms to profit from their R&D investments, the level of R&D that would maximize firms' profits could still fall short of the level that would be best for society. Society's benefits would include the value of any new innovations that were inspired by the patented invention but that were not covered by the patent, and the extent to which the benefits created by the patented invention (theoretically measured by an individual's willingness to pay for it) exceeded the price charged for it.

The divergence between private profits from R&D and social gains is not unique to investments designed to reduce carbon emissions. Rather, that divergence is characteristic of R&D investments in general—particularly for basic research and less so for research that is more clearly linked to commercial applications. Measuring the gap between firms' profits from R&D and society's benefits is difficult, but some analysts think that it could be quite large.[12] Should the gap between social benefits and private profits be less than those researchers estimated, the efficiency gains from subsidizing private R&D efforts would be diminished.

The Costs of Supporting R&D

Determining the appropriate amount of resources to devote to subsidizing research efforts is complicated by the fact that research can be costly and outcomes are uncertain. Federal funds devoted to R&D would impose an opportunity cost in that they could not be used for other spending priorities, to lower taxes, or to reduce the deficit. Further, federal funds devoted to inducing more R&D on alternative energy technologies or sequestration could impose a second opportunity cost by "crowding out" R&D in other sectors of the economy. For example, such policies might discourage private R&D spending by coal extraction firms or in other, seemingly unrelated, industries, such as civil engineering and computer software. The latter effect might occur because the policy-induced R&D in one area could bid up the price of key research inputs, such as highly qualified engineers,

11. For a more complete description of these and other ideas, see Kenneth Caldeira and others, *Climate Change Technology Exploratory Research* (Washington, D.C.: Climate Policy Center, December 2005).

12. Estimates of social rates of return (society's benefits) resulting from private investments in research and development are highly uncertain, but some researchers suggest that they average as much as 30 percent to 50 percent. In contrast, private marginal rates of return are estimated to be between 7 percent and 15 percent. See research cited in David Popp, *R&D Subsidies and Climate Policy: Is There a 'Free Lunch'?* Working Paper No. 10880 (Cambridge, Mass.: National Bureau of Economic Research, October 2004), p. 4; and Edward Mansfield, "Macroeconomic Policy and Technological Change," in J.C. Fuhrere and J. Sneddon Little, eds., *Technology and Growth, Conference Proceedings (*Boston, Mass.: Federal Reserve Bank of Boston, 1996), p. 191.

Box 2-3.

Using Prizes to Encourage Technological Improvements

The federal government has traditionally funded research and development through the use of tax credits; research grants or contracts to private or academic institutions; or research at federally funded facilities, such as the national laboratories. Such means of funding subsidize the cost of conducting the research rather than provide a monetary award for a successful outcome.

In recent years, analysts and policymakers have considered using prizes as a way to spur technological improvements that would lower the cost of reducing carbon dioxide emissions—such as improvements in energy efficiency, renewable energy sources, or the development of fundamentally new energy sources that emit no carbon dioxide.[1] Prizes have been used to a limited extent to encourage technological developments for hundreds of years. One of the earliest well-known uses of prizes was an award offered by the British government to inventors who designed instruments capable of accurately measuring longitude. In that case, the goal was to reduce the number of ships lost by the Royal Navy. A more-recent example of a federally funded prize is the Defense Advanced Research Projects Agency's "Grand Challenge." That prize, awarded for the development of driverless vehicles, aims to reduce battlefield casualties of U.S. troops. Several prizes have been offered by private entities as well, leading to technological improvements in the areas of aviation and automobiles, among others.

The use of prizes has several advantages over cost-subsidizing approaches:

- Firms that conduct the research bear the risk of failure—that is, they absorb the costs of unsuccessful endeavors. Having researchers, rather than the federal government, bear those costs makes sense for at least two reasons: researchers are likely to have better information on the likelihood of the success of different endeavors, and the research facility itself has the most control over whether it is spending its research dollars effectively.

- Federal award money is directly linked to a successful outcome, with the winning firm unknown at the outset. As a result, federal money could be less influenced by competing goals that policymakers might have, such as providing employment or research facilities for their states or districts.

- If prizes entail fewer bureaucratic hurdles than the traditional grant or contract process, then they may encourage the participation of smaller firms, those without previous involvement in federally funded research efforts, or both. Some anecdotal evidence indicates that technological breakthroughs are more likely to come from more unorthodox entities.

- The prestige associated with winning a competition can offer firms a further incentive to participate.

The use of prizes can have disadvantages as well:

- If the technological improvements sought are risky and expensive, then the prizes necessary to induce them would need to be large.

- If the necessary research is thought to be expensive, then the use of prizes could actually discourage the participation of smaller research entities, which could not cover the costs themselves and may not have access to credit.

1. For a more detailed discussion of the points made in this box, see the statement of Douglas Holtz-Eakin, Director, Congressional Budget Office, *Economic and Budgetary Issues with Cash Prizes to Achieve NASA's Objectives,* before the Subcommittee on Space and Aeronautics, Committee on Science, U.S. House of Representatives (July 15, 2004); and Richard G. Newell and Nathan E. Wilson, "Technology Prizes for Climate Change Mitigation," Discussion Paper 05-33 (Washington, D.C.: Resources for the Future, 2005).

Box 2-3.

Continued

- If an award attracted many participants, resources could be wasted as researchers duplicated one another's efforts. While relevant, this limitation is not restricted to prizes. Such duplication can occur as firms attempt to be the first to patent an outcome as well. That problem could be reduced by structuring the competition so that the number of competitors is narrowed over time (through the use of intermediary hurdles) or by requiring competitors to pay to participate.

- Firms would be reluctant to participate if they thought that the government might renege on the prize if attitudes toward the prize's goals changed. To avoid such a possibility, the government could establish a private-sector escrow account or purchase an insurance policy that would guarantee that the funds would be available.

At least four different design considerations may influence the likelihood that offering a prize will lead to technological improvements. First, the technological target must be as specific and measurable as possible, yet broad enough to allow for creative efforts. Capturing the correct balance could be difficult. For example, a general goal of reducing carbon dioxide emissions at a given cost could lead to a wide variety of technological innovations. Some may clearly be more desirable than others, though, because they would increase—or reduce—other forms of pollution (such as nuclear waste). Policymakers may want to take those other costs into account and to specify such considerations beforehand. Focusing climate technology prizes on one research area (such as solar energy) at a time may provide one possible solution.

Second, the amount of the prize must be set sufficiently high to induce participation, but not so high as to provide excessive rewards. Finding the correct balance could be difficult, particularly if the competition is expected to last for an extended period. As described in the main text of this paper, the private rewards from firms' innovations (that is, their profit-making potential) are determined by the market for carbon-reducing technologies, which, in turn, depends on government policies. Should policies that provide incentives for carbon reductions emerge in the future, the private rewards from firms' innovations would be higher than if such policies did not emerge. Ensuring—or restricting—firms' access to patents for their innovations is one way that policymakers could influence both the amount of the prize and the public availability of the research outcomes. Allowing winning firms to patent their innovations would increase the number of participants, reduce the magnitude of the prize necessary to ensure participation, or both. However, it would also limit the availability of the technology to the public. Further, private firms are likely to have more information about the costs that research endeavors might entail than the policymakers who are responsible for setting the magnitude of the reward. Some researchers have suggested that the latter problem might be resolved by letting researchers bid for the size of the prize they would accept if their efforts were successful.

Third, the conditions for winning would influence the speed and quality of the outcomes. A contest with a cash award could be structured as a tournament (contest) or as a race (first past the post). A tournament, which specifies an objective and a time limit, guarantees an award to the party that has made the most progress toward the specified goals. It encourages participation—parties with substantial uncertainty may enter on the basis of partial insights—but can impose high costs on the government for evaluating many participants' relative progress toward the stated goals. In contrast, a race specifies a well-defined goal (the post to pass) and makes an award only if that goal is achieved. A downside of a race is that it could reward a suboptimal outcome because a competitor who was developing a superior technology may finish second.

Finally, clarity in the rules is essential. Unclear or unenforceable rules can lead to costly litigation and reduce incentives to participate.

computer experts, and scientists.[13] Although the magnitude of that effect is unknown, it could be significant. Finally, identifying investments with the highest potential returns can be challenging, although federally funded prizes have been suggested as one method of doing so (see Box 2-3 on pages 12 and 13).

Studies have reached conflicting conclusions about whether or not fundamentally new technologies for providing carbon-free energy, or for sequestering emissions, would be necessary to prevent the concentration of carbon in the atmosphere from exceeding targeted levels.[14] Such studies, however, provide little guidance for R&D funding decisions because they do not consider either the costs or the benefits of developing the new technologies.

Current Policies That Support R&D

Two tax provisions encourage firms' R&D efforts, thereby increasing the level of R&D they undertake:[15]

- Firms may receive a nonrefundable 20 percent income tax credit for certain research expenditures (such as salaries, time-sharing costs for computers, and contracts). That provision has expired but is expected to be extended.[16]

- Firms may deduct certain research expenditures as a current business expense, even though those expenditures are likely to generate patents with a useful life extending beyond a single tax year.

Those provisions are designed to encourage firms to undertake research on all different forms of technology improvements, not just ones that would reduce carbon emissions. Such tax provisions can increase the profitability of firms' R&D efforts but cannot make up for the lack of a market for a new technology. Thus, in the absence of carbon pricing, those tax provisions would be unlikely to motivate firms to undertake R&D on carbon-reducing technologies that would not be profitable for other reasons (such as rising energy prices). Should carbon pricing be implemented, however, those tax provisions could help boost the amount of investment by closing the gap between private and social gains from the development of new carbon-reducing technologies.

In addition to those tax provisions, the federal government directly funds research that could lead to lower carbon emissions. Examples include research aimed at making advances in producing energy from nuclear fuels, hydrogen, and renewable fuels (such as biomass and solar) as well as efforts to improve the energy efficiency of vehicles, buildings, and industrial processes.

In the absence of carbon pricing, federal support for research on carbon-reducing technologies could help make up for the lack of a profit motive for private firms to undertake such efforts as well as the spillover benefits that private research would have generated. Thus, the efficient amount of federal R&D funding depends, in part, on whether or not policymakers establish policies, such as a carbon tax or cap, that create incentives for private firms to invest in new technologies.[17]

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13. See Austin Goolsbee, "Does Government R&D Policy Mainly Benefit Scientists and Engineers?" *American Economic Review,* vol. 88 (1988), pp. 298-302.

14. For example, one study concluded that incremental improvements in existing technologies could limit carbon emissions over the next 50 years to a trajectory that would avoid a doubling of the pre-industrial concentration. See S. Pacala and R. Scolow, "Stabilization Wedges: Solving the Climate Problem for the Next 50 Years with Current Technologies," *Science*, vol. 305 (August 13, 2004). In contrast, another study concluded that currently known technologies have severe deficiencies that limit their ability to stabilize the global climate. See Martin I. Hoffert and others, "Advanced Technology Paths to Global Climate Stability: Energy for a Greenhouse Planet," *Science*, vol. 298 (November 1, 2002).

15. See Congressional Research Service, *Tax Expenditures: Compendium of Background Material on Individual Provisions* (S.PRT. 108-54), pp. 59-70.

16. Since 1981, when this tax credit was first enacted, it has been extended 10 times, most recently through December 31, 2005. Although the statutory rate of the credit is 20 percent, the actual cost reduction is less than 20 percent (13 percent for some expenditures and 6.5 percent for others) because of certain rules governing how the credit is computed.

17. In the absence of carbon pricing, the research subsidy would simultaneously reduce the distortions in research incentives caused by two market failures. See Lawrence H. Goulder and Stephen H. Schneider, "Induced Technological Change and the Attractiveness of CO_2 Abatement Policies," *Resource and Energy Economics*, vol. 21 (1999), pp. 211-253.

CHAPTER

3

The Effectiveness of Policy Approaches

The policy tools for reducing carbon dioxide emissions include pricing such emissions to discourage the use of fossil fuels and subsidizing the research and development of technologies that would reduce emissions. Those policy tools could be used individually or together (either simultaneously or sequentially). The empirical evidence available to evaluate policy options is limited, but that which is available can be used to inform simulation models. Those models can be used to compare the potential for R&D subsidies and carbon-pricing policies to increase net benefits from reducing carbon emissions or to evaluate the costs of achieving a given target for emissions. Those simulations suggest that the most efficient means of reducing carbon emissions would include applying both policy tools simultaneously; the gains from R&D alone would be unlikely to eliminate the value of near-term reductions in emissions and, thus, to obviate the benefits of near-term pricing.

Policy Simulations

The basic approach of models that simulate climate change policies is to measure the trade-off between consumption today and consumption in the future—where consumption is broadly defined to include the value of goods sold in markets, such as agricultural products, and the value of nonmarketed goods, such as ecosystems or longer life spans. Efforts to limit greenhouse gases in the near term would reduce the amount of resources that could be devoted to current consumption or to other investments. However, because those efforts are undertaken to reduce potential climate change damages in subsequent time periods, they lead to greater consumption in the future.

Policies are "efficient" if they maximize the present value of consumption over time. In other words, efficient policies would achieve the best balance between the reduction in current consumption that would result from today's carbon-reducing policies (policy costs) and the increase in consumption—measured in present-value terms—that future generations might enjoy as a result of those policies (policy benefits). Alternatively, policies may efficiently meet a given emissions-reduction target if they do so with the lowest possible reduction in consumption over time.

Although simulation models are the best method currently available to evaluate policy options that address climate change, they are beset by uncertainties. Key uncertainties associated with measuring the costs of policy options include:

- The magnitude of emissions in the absence of policies—the lower those emissions are expected to be, the fewer reductions will be needed to meet a given target and the lower the costs will be;
- The costs of achieving a given reduction in emissions; and
- The effectiveness of policy tools in bringing about the lowest-cost reductions at a given point in time or in stimulating the development of new technologies.

Key uncertainties associated with measuring the benefits of policy options include:

- The effects of reductions in carbon emissions on the average global temperature;
- The distribution of reductions in global temperatures across seasons and regions, and the effects of those changes on other characteristics of climate, such as rainfall, severity of storms, and sea level;
- The effects of changes in regional climates on natural and human systems, such as agricultural crops, property, species, and human health; and

- The valuation of policy-induced reductions in damages to natural and human systems.[1]

Given the tremendous uncertainties involved in measuring policy costs and benefits, quantitative recommendations about the most efficient levels of prices or R&D subsidies are liable to be highly inaccurate. Qualitative policy recommendations about the appropriate timing, or relative importance, of policies are most robust if different modeling efforts reach similar conclusions or if a given model comes to the same qualitative conclusion when key assumptions are altered over the relevant range of potential values.

Results

The Congressional Budget Office identified three published analyses that simulate the effects of both emissions pricing and R&D.[2] While CBO recognizes the limitations of those modeling efforts and does not endorse any specific quantitative results, those models suggest that a combination of the two approaches—pricing emissions in the near term and funding R&D—would be necessary to reduce carbon emissions at the lowest possible cost. Further, they suggest that the largest gains in efficiency are likely to come from pricing emissions rather than from funding R&D. The simulation results described below reflect policies that are implemented at the global level.

One modeling effort concluded that the net benefits resulting from an R&D policy that balanced the costs and benefits of R&D efforts would be less than half of the net benefits that would result from an efficient carbon tax policy with no R&D subsidies.[3] Further, that effort found that the R&D policy would not reduce the benefits of near-term pricing of carbon because it would not reduce the value of near-term reductions in emissions. Two limitations of that modeling effort are that it did not examine the combined effects of the two policies, and it did not include an alternative energy technology (such as solar or wind generation); rather, R&D subsidies led to improvements in energy efficiency.[4]

A second researcher, using a model that included the possibility that R&D could improve both energy efficiency and an alternative energy technology, found that subsidizing R&D would provide only a small increase in net benefits relative to the maximum gains available if policymakers enacted only an efficient carbon-pricing policy.[5] Further, the results suggested that subsidizing R&D would cause little change in the efficient price of emissions, or the amount of reductions, in the near term. To test the sensitivity of the findings to changes in assumptions, the researcher assumed that the additional R&D induced by subsidies would not crowd out any other research. That assumption did not change the researcher's qualitative results.[6]

1. See Congressional Budget Office, *Uncertainty in Analyzing Climate Change: Policy Implications* (January 2005), for a more detailed discussion of the uncertainties associated with the costs and benefits of climate policies.

2. Those models assume that carbon pricing would stimulate less private investment in R&D than would be best for society given the existence of spillover benefits. Further, they assume that public funds would subsidize private R&D efforts. Their conclusions, therefore, do not stem from assumptions about the success or failure of federal R&D programs.

3. R&D benefits were assumed to include both spillover benefits and the reduction in external costs that would result from the new technologies.

4. That modeling effort also estimated that an efficient tax on carbon emissions would lead to about twice the level of reductions in emissions that would result from an efficient R&D subsidy. See William D. Nordhaus, "Modeling Induced Innovation in Climate Change Policy," in A. Grubler, N. Nakicenovic, and W.D. Nordhaus, eds., *Modeling Induced Innovation in Climate Change Policy* (Washington, D.C.: Resources for the Future Press, 2002). Nordhaus assumes that technology improvements are exogenous in the carbon-tax-only case.

5. Net benefits increased by 7 percent when R&D subsidies were added to a carbon-pricing policy. See David Popp, "Entice-BR: The Effects of Backstop Technology and R&D on Climate Policy Models," *Energy Economics*, vol. 28 (2006), pp. 188-222. Popp does not report the change in efficient prices and emissions reductions under the sensitivity analysis. Another analysis (which did not include a backstop technology) by Popp found that the net benefits associated with an efficient R&D subsidy were only 11 percent of the maximum gains available with an efficient carbon-pricing policy and an efficient R&D subsidy. In contrast, the net benefits associated with the carbon-tax-only case were 95 percent of the potential maximum gains. To test the robustness of his results, Popp assumed that the returns to energy R&D were twice as high as the returns to other forms of R&D, and under that assumption he still found that the net benefits of an efficient R&D strategy would amount to less than 55 percent of the potential gains from the combined pricing/R&D subsidy approach. See David Popp, *R&D Subsidies and Climate Policy: Is There a 'Free Lunch'?* Working Paper No. 10880 (Cambridge, Mass.: National Bureau of Economic Research, October 2004).

6. Under that assumption, Popp found that an R&D subsidy would increase potential net benefits by an additional 30 percent.

A third modeling effort examined the ability of carbon pricing and R&D subsidies to minimize the cost of achieving a specific reduction in carbon emissions—in this case, 15 percent—rather than to maximize net benefits. That effort concluded that carbon pricing would achieve the target at a significantly lower cost than would an R&D subsidy for alternative energy sources. The cost of achieving the reductions with a carbon tax was roughly 11 percent of the cost of achieving the reductions with an R&D subsidy. Further, combining both policies would reduce the cost of achieving the emissions target by only 9 percent when compared with the cost of reaching it with only a carbon tax.[7]

Those models suggest that pricing emissions would contribute more to minimizing the cost of reducing emissions than would subsidizing investments in R&D. Given the uncertainties described above and the global nature of the simulation models, the quantitative results of such models should be viewed as very imprecise and corresponding conclusions about domestic policies should be made with caution. However, the qualitative finding that a cost-effective approach to reducing emissions would entail both funding R&D and pricing carbon in the near term is likely to be robust for several reasons:

- At any point in time, there is a cost continuum for emissions reductions, ranging from low-cost to high-cost opportunities. Unless R&D efforts were to virtually eliminate the value of near-term reductions in emissions, waiting to begin initial pricing (to encourage low-cost reductions) would increase the overall long-run cost of reducing emissions. Given reasonable assumptions about the costs of and gains from near-term R&D, the possibility that R&D would eliminate the value of near-term emissions reductions appears unlikely.

- Both pricing emissions and funding R&D would impose costs on the economy. Consequently, reducing emissions in the most cost-effective way would entail balancing the costs—and the expected payoffs—of both policies.

- Analyses that consider the costs and benefits of both carbon pricing and R&D all come to the same qualitative conclusion: near-term pricing of carbon emissions is an element of a cost-effective policy approach. That result holds even though studies make different assumptions about the availability of alternative energy technologies, the amount of crowding out caused by federal subsidies, and the form of the policy target (maximizing net benefits versus minimizing the cost of reaching a target).

The models described above are not well suited to account for the possibility that greenhouse gases could build up to a critical level, or threshold, in the atmosphere and thus could trigger a rapid increase in damages. Some analysts suggest the potential existence of such a threshold could call into question the value of making near-term reductions using existing technologies. In order to avoid passing such a threshold, it may be necessary to develop fundamentally new technologies that could provide a large share of the world's energy needs without releasing carbon or that could sequester similarly large shares of carbon emissions. Near-term pricing of emissions would impose costs on the economy but would not ultimately prevent any such threshold from being crossed—and large-scale damages from occurring. However, near-term pricing could have substantial value even under such circumstances. That value could stem from three sources:

- Near-term reductions in emissions could delay the crossing of a critical threshold and thus the point at which severe damages might occur. That delay has intrinsic value because the farther in the future that damages occur, the less value they have in the present.[8]

7. See Stephen H. Schneider and Lawrence H. Goulder, "Achieving Low-Cost Emissions Targets," *Nature,* vol. 489 (September 1997), pp. 13-14. In addition, those researchers demonstrated that the merits of a tax and of R&D subsidies are sensitive to the magnitude of prior distortions created by existing subsidies to R&D for alternative and fossil-fuel-based energy. A carbon tax can help undo, or exacerbate, an existing imbalance between incentives for R&D on alternative and fossil fuels. Further, the desirability of subsidizing R&D on alternative energy technologies depends not only on the existence of knowledge spillovers from such research, but on the magnitude of those spillover benefits relative to spillover benefits from R&D in other sectors and on whether a carbon tax is in place. See Lawrence H. Goulder and Stephen H. Schneider, "Induced Technological Change and the Attractiveness of CO_2 Abatement Policies," *Resource and Energy Economics*, vol. 21 (1999), pp. 211-253.

8. Future damages are discounted to reflect the fact that, in a growing economy, future generations would have more resources with which to address such damages.

- Near-term reductions in emissions could allow time for fundamentally new technologies to be developed and put in place. That additional time could be essential to avoid crossing a critical threshold, given that the timing, and eventual outcomes, of R&D efforts are highly uncertain and that the process of putting new energy systems in place could be slow and costly.

- Near-term pricing could motivate current reductions in emissions whose cost is less than the present value of the expected (but uncertain) cost of reducing emissions using future technologies.

Limitations

Determining the appropriate mix of policies to address climate change is complicated by the fact that future policies would be layered on a complex mix of current and past policies, all of which affect the use of fossil fuels and their alternatives. Current policies subsidize the production and use of both fossil fuels and their alternatives. In addition, other existing federal, state, and local policies influence decisions about fossil fuels in less direct ways. While those existing policies serve other objectives, they also influence current and future carbon emissions.

The models that estimate the costs and benefits of pricing carbon emissions do not account for existing policies, and it is unclear how the quantitative conclusions of those models would be altered by their inclusion. The qualitative conclusion that a gradually increasing price on carbon emissions is likely to help minimize the costs of reducing carbon emissions is likely to be robust. No current policy attaches a cost to all fuels on the basis of their contribution to climate change; as a result, firms, households, governments, and other organizations do not face an incentive to take those costs into account in their production and consumption activities.

The picture for federal subsidies for R&D is also complex. New technologies are eligible for patents and are currently subsidized through general tax credits for R&D expenses. In addition, the federal government provides direct funding for some low-carbon energy sources, such as solar, nuclear, and wind power. Determining whether the magnitude of those subsidies, or the design and direction of the federal subsidy program, is appropriate is beyond the scope of this paper. To the extent that there are additional spillover benefits from R&D on carbon-reducing technologies, providing additional subsidies for R&D could be efficient.[9] Further, in the absence of carbon pricing, an R&D subsidy for carbon-reducing technologies could be justified by the external costs of carbon emissions; however, an R&D subsidy would offer a less direct method of reducing those external costs.

Administering a carbon-pricing program or initiating a larger R&D program for carbon-reducing technologies would entail costs. A full accounting of policy costs would entail weighing those administrative costs against the increase in net benefits that the policy would create. Available research indicates that the costs of implementing a carbon cap-and-trade program, or a tax on carbon emissions, are likely to vary significantly depending on where the cap, or tax, is placed. Placing the cap, or tax, upstream—on fossil fuel producers and importers—could minimize program costs. An upstream design could also provide incentives for firms to sequester carbon, as well as reduce their emissions, but the costs of implementation would probably be higher.[10]

Further, the models described above assume that policies are implemented in a perfect fashion. For example, they assume that a carbon tax would equalize the costs of reductions in emissions across all sources at a given point and would, in the absence of spillover benefits, lead to efficient investments in new technologies. In the case of R&D subsidies, they assume that federal subsidies would augment private R&D efforts up to the efficient point, with no distortions in the type of research that would be conducted, and that once the new technologies were developed, their cost savings would be fully captured. In re-

9. In the absence of additional R&D subsidies, relatively large spillover benefits from R&D on carbon-reducing technologies could also reduce the economic costs of a carbon tax. By redirecting research toward those technologies, the carbon tax would both internalize the costs of carbon emissions and help reduce the under-funding of private research efforts (due to unaddressed spillover benefits) in that area. For a discussion of that point, see Goulder and Schneider, "Induced Technological Change and the Attractiveness of CO_2 Abatement Policies." Further, if spillover benefits (what remained after accounting for existing subsidies) are small for R&D on carbon-reducing technologies (relative to other types of R&D), then providing additional subsidies for R&D on carbon-reducing technologies could be inefficient in that it could crowd out higher-valued research in other areas.

10. For a discussion of implementation issues, see Congressional Budget Office, *An Evaluation of Cap-and-Trade Programs for Reducing U.S. Carbon Emissions* (June 2001) and CBO's Comments on the White Paper "Design Elements of a Mandatory Market-Based Greenhouse Gas Regulatory System" (March 12, 2006).

ality, both policies would fall short of that theoretical ideal.

Finally, this study discusses policies designed to reduce carbon emissions in the United States. However, the causes and consequences of climate change are global, and the most cost-effective mitigation policies would require coordinated international efforts. Policies designed to promote low-cost reductions in emissions in rapidly developing countries, such as India and China, will be an important part of the policy mix for addressing climate change, though they are not addressed in this paper. If a domestic carbon-pricing program led to significant increases in the prices of U.S.-produced goods that were not matched by other countries, then carbon-intensive industries might choose to relocate to countries that do not have similar restrictions, diminishing the effectiveness of a U.S. carbon-pricing program. Adjusting the cap or tax to offset those effects could increase the cost of administering the program. Conversely, the establishment of a U.S. carbon-pricing program could affect the incentives of other countries to adopt similar restrictions. Moreover, successful domestic R&D efforts would lower the costs of reducing carbon emissions in other countries as well as within the United States. The extent to which those new technologies would be deployed at home and abroad would depend on whether incentives to reduce carbon emissions were put in place, or whether they could be cost-effective for other reasons, such as by providing energy at a lower cost than existing fossil fuel sources.

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